The Annual Growth In Plants

by J. E. Courtright

1903

Submitted to the Graduate School of the University of Kansas in partial fulfillment of the requirements for the Degree of Master of Science

The Annual Growth in Plants

The two great functions which are laid down by scientists as the main activities of plants are nutrition and reproduction. Upon these depend the size, character, life and length of life of the individual. The former looks to self preservation. The latter look to the preservation of the species and is the objective point of the plants normal existence.

Thus reproduction determines the length of time it is necessary that a plant should live in order to reproduce the species. In other words it determines whether a plant is an annual a biennial or a perennial and whether the plant lives over until the next growing season as a seed, a root, a bulb, an underground stem or as an entire plant. It determines whether a plant must ~~life~~ live and grow year after year in order to reproduce the species like the elm, oak, spruce and other great forest trees or like the corn and the sunflower may spring up, reach maturity and die again every year. In this sense reproduction determines annual growth.

Nutrition on the other hand may be said to determine growth in plants by causing variations in size and structure both internal and external. In the sense used here it may also be said to include everything necessary for the life and growth of the plant. Growth as determined by nutrition means growth as determined by the available supply of water, carbondioxide, oxygen, nitrogen in the form of nitrates and nitrites and likewise the compounds of potassium iron, sulphur, phosphorus, magnesium and calcium. Among these the one thing which shows the greatest effect upon plants in nature is the presence or absense of the water which goes to make up the carbohydrates, the first of all the compounds produced in the plants manufactory and upon which all plants depend as the great solvent for the transportation of both raw materials from the roots to the leaves and of the manufactured materials from the leaves to all parts of the plant. To be sure the carbon from the CO_2 of the air is necessary for these food compounds but since the CO_2 is in the air it is everywhere. Water on the other hand, in most localities, is a variable quantity. Its amount and constancy of distribution determine what sort of vegetation will grow in each locality. It forms the basis for determining the great plant societies, the xerophytes of the arid regions, the hydrophytes of the wet swampy or lake regions and the mesophytes of the great middle region. Even in the evolution of plants water has played a very important part and we may therefore expect some noticeable effects as the amount varies from season to season.

In so taking up the influence of the water supply upon plants we do not intend to imply however that other things also are not of great importance. Environment, soil, temperature, sunlight, wind etc. all have an extremely great influence upon plants but the influence of water is greater because of, as we have said before, its great necessity and yet varying quantity.

It might be well to state here before we go any farther that it is the intention in this paper to take up only the higher plants for it is evident that what we can term annual growth can take place only in those plants in which there is but a single generation in a year or number of years. This necessarily excludes all of the lower cryptogamic plants. Yeasts, bacteria, algae and most of the fungi reach the fullest development of which they are capable, under favorable conditions in a few days, hours or even minutes. Tens or hundreds of generations may pass within a single year. Considered as individuals there can be nothing here which corresponds to annual growth. Considered in the aggregate the generations fluctuate in numbers with the changes of temprature and moisture of the seasons. They may also go into resting or spore stages for winter but the same thing may be true whenever they find themselves in adverse conditions. It is only in those changes due to adverse conditions; changes which the species as a whole undergo, that we may find a resemblance to the changes which higher plants undergo in like conditions. Thus the preparation of the higher plants to stand drouth or winter conditions corresponds as a preparations for adverse conditions. The determination of the growth of plants hinges therefore upon the way a plant meets these conditions and must depend upon the two great functions mentioned in the beginning, nutrition and reproduction.

Let us return more directly to the subject. With the object of learning something of the effect of various conditions environments etc. upon plant life during the summer of nineteen hundred and two observations were made and material collected for microscopical study from four different localities. For convenience in speaking of the different localities let them be designated as A B C and D. A was an upland region with a light, grayish clay soil. B was an upland region with a hard, tough, gravelly clay soil commonly known as hard pans or gumbo. C was an upland region with a black limestone soil. D was a lowland illuvial region covered with native forest trees. The end in view in undertaking the experiments was to determine especially the effect of the variations in the available water supply in the different localities upon the growth and structure of the plants.

Observations were taken upon the amount of moisture in the soil and the amount of evaporation directly above the soil. A record was obtained from a weather station near at hand for the same period for the amount of rainfall, mean temprature, wind and cloudiness for each day. The soil tests were taken at the depths of two inches, four inches one foot, two feet, ~~and~~ three feet and four feet. Evaporation tests were taken directly above the surface of the soil in order to determine the relative amounts of moisture which each soil was giving up by evaporation and the freedom or reluctance with which it gave up the moisture. The experiments were caried on during the height of the growing season, beginning in the latter part of July and running through August and up to the early part of September. The material which was collected for microscopical study during this period was from plants which were as nearly as possible at the same period in their developement Annuals being chosen which were at the height of flowering and the sections from every tree being taken from the same relative positions on the branches.

On the opposite page is given a table for a part of the period. In the evaporation tests it was not the intention to follow each day separatly so much as to obtain for the entire

Da. Aug.	Station A	Station B	Station C	Rain	Wind	Temp.	Cloudiness	
	Evaporation at soil surface							
1	2-75	4-416			NE	68	.06	
2	2-75	4-416	No good		S	76	18.	
3	2-80	4-418			S	85.5	.00	
4	3-485	5-920	4-470	Eight-da. between rains	S	86	.00	
5	3-485	5-920	4470		S	87	.00	
	3-490	5-920	4-470		S	87.5	.00	
7	3490	5-920	4470		S	86.5	.00	
	No good	6.270	7-415		S	90	.10	
		6.270	7-415	.03	S	82	.06	
					S	85	.19	Soil test-
1		Interrupted by rain		1.75	E	76	27.00	
2				.10	E	78.5	18.00	
3				T	NE	77.5	25.00	
4				.11	E	80	12.00	
5					S	84	.00	Soil test-
					S	86.5	10.	
7				-.82	N	71	90	
	1-840	3-55	4960		NE	75.5	20	
	1-835	370	4980		E	75	.05	
	Interrupted by rain.			1.81	SE	81.5	.04	Soil test-
					SW	75.5	30.	
24				.68	NE	70.5	24.	
	2-710	2-395	2-115		E	70	10.	
	2-710	2-395	2115		NE	75	.05	~~soil test~~
	2-795	2-600	3-470		NE	62.5	00	

Upon the basis of 30 as entire cloudiness period the relative rates of evaporation for the period from the different soils.

Summing up for the whole time the rates were as follows:- Average rate of evaporation at the surface of the soil for the whole period at station A, 2.06886 grams of water per day per square inch of free surface; at station B 3.43724 grams per day; at station C 3.58113 grams per day: at station D 1.5360 grams per day. Computed for an acre of ground at each station the results are as follows:- at station A 12,983,814.8220 grams or fourteen tons of water per day; at station B 21,572,568.2816 grams or a little over twenty three tons; at station C 22,160,806.8992 grams or twenty four tons per day; at station D 9,639,688.24 grams or ten tons per day.

The result at first sight seems rather peculiar that the highest rate of evaporation should be reached at a station like C with a soil of loose black limestone loam while that at B should be second highest with a tough gravelly clay soil and in addition that a station like A with a light clay soil should run below either B or C. The same thing is to be noticed in regard to the highest daily average. On the nineteenth of August after eight days of continuous dry weather with a strong wind from the south and the thermometer standing at a mean tenprature of 90° Farenheit the evaporation at B and C rose to the enormous amounts of 38.5 and 50 tons per acre respectively while that at A never reached more than about 30 tons per acre. The fact that the evaporation at D fell to 10 tons per acre is not so surprising however since both the sun and the wind were shut out to a large extent by the trees while at the other stations the exposure to sun and wind was made as nearly as possible equal throughout.

The soil tests give us the explainations for the variations. The one taken just at the end of the dry spell spoken of in the preceding for all four stations is as follows:-

Percentage of moisture in soils at different depths

A.	B.	C.	D.
10. at 2 in.	1.9 at 2 in.	5.94 at 2 in.	3.3 at 2 in
10.09 at 4 in.	5.7 at 4 in.	9.12 at 4 in.	8.4 at 4 in
10.05 at 1 ft.	6.94 at 1 ft.	12. at 1 ft	6.74 at 1 ft
10.[illegible] at 2 ft.	10.07 at 2 ft.	12.02 at 2 ft	7.8 at 2 ft

The result needs no comment to show the conditions of the soils at the different locations. Another test taken later after the soil had received a good rain gave the following results:—

A	B	C	D
11.9 at 2 in	11.5 at 2 in.	15.3 at 2 in.	18.6 at 2 in.
13.5 at 4 in	7.7 at 4 in.	17.9 at 4 in.	17.3 at 4 in.
10.4 at 1 ft	9.7 at 1 ft.	17.8 at 1 ft.	9.3 at 1 ft.
12.6 at 2 ft	11.8 at 2 ft.		9.06 at 2 ft.

From these two tests can be gained an idea of the general result for the entire period. The moisture at A down to the depth of one foot always ranged above ten percent and usually varied but little at different depths. The moisture at B down to the depth of one foot rarely reached ten percent. It ran as low as that given in the first test above and usually ranged between five and eight percent. A test taken at this station on August thirtieth after nearly two inches of rain showed the following result:- at 2 in 34.28 percent; at 4 in. 6.28 percent; at one foot 6.7 percent; at two feet 9.7 percent. The reason why the percentage of moisture began to increase at the depth of two feet was that water came up from an underground stream about seven feet below. Yet this added to the supply from rains was never able to saturate the soil above to more than the ~~depth~~ average of about seven percent and then this was rapidly reduced by evaporation. Station C at the depth of one foot never showed a moisture of less than twelve percent and usually stood above that; yet in dry weather the moisture within two inches of the surface might fall to six percent. Station D showed a great irregularity at various depths and a great range of percentages. This was probably due to the demands the forest trees made upon it and their deep rooting character.

Comparing the amounts of moisture in the soils and the rate of evaporation at the surface the results seem to lead to these conclusions. The soil at station A absorbs moisture readily and gives it up to evaporation again fairly rapidly. The soil at B absorbs moisture slowly and lets it evaporate again rapidly. The soil at station C absorbs moisture readily and gives it up to evaporation very slowly.

The soil at station D absorbs moisture readily and gives it up to evaporation slowly because of the thick shade of the trees.

Since we now have some idea of the conditions of the water supply which the different locations offer to plants let us investigate the character of the vegetation. The native plants will very likely give us the best comparisons for they will be of the type best addapted to each location. At station A were such as the following:- Amaranthus two species, Xanthium two species, crotton one species (very plentiful) Datura stramonium, Erigeron Canadensis, Ambrosia trifida and artemisifolia, Helianthus annus, Polygonium Pensylvanicum, Solidado Canadensis, Bidens coronata, Cassia chamachrista, Abutilon abutilon, Panicum sanguinale and crus-galli and Populus monilifera.

The flora at station C was similar to A except that the growth was more vigorous

The flora at station B was almost entirely zerophytic:- Talinum teretifolium, Portulaca pilosa, Opuntia tortispina, Croton capitatus, Ambrosia artemisifolia, Bouteloua hirsuta & Eleusine Egyptium, and other things characteristic of the arid regions.

The flora at station D was of an entirely different character, forest trees and shade loving plants almost altogether:- Alnus Americana and fulva, Juglans nigra and olivaeformus, Cercis Canadensis, Sambucus Canadensis, Salix nigra, Celtis occidentalis, Sapindus marginatus, Gleditchia tricanthos, Prunus Americana and serotina, Fraxinus lanceolata (?), and climbing plants such as Cissus ampelopsis, Vitis cordifolia and Rhus toxicodendron. In the shade below Violas, Ranunculas, Desmodiums Polygonums and many others of the same character.

That the water supply in determining the character of vegetation generally is of the most vital importance is evident. In it we find largely the cause for the great modifications shown by plants in different localities. From our observations we believe we are justified in concluding that the presence of water enough to keep the soil fairly well saturated leads to the growth of trees and especially the woody parts of plants. As the water supply increases the trees become lighter in proportionate weight and are finally superceded by water plants whose tissues are very largely taken up by air passages and intercellular spaces. As we approach the arid regions there seems to be less differentiation into wood and xylem and more into bark or cortex. For example a plant, Talinum teretifolium especially suited to dry regions and characteristic of region B of the preceding showed fiftyseven percent of the diameter in cross section to bark or cortex and the remainder fortytwo and ninetynine hundredths percent showed but little differentiation into xylem or for water conducting. The sunflower, Helianthus annus which was found growing in both regions B and C showed the following differences in this respect:-

	Bark	Wood	Pith
At station B	16.62 %	19.09 %	64.29 %
" " C	11.62 "	24.11 "	64.27 "

Where ever comparisons could be obtained for other plants variations of the same sort occured. Xanthium Canadensis Erigeron Canadensis and Solidago Canadensis showed the following:

Dry region	Bark	Wood	Pith
Xanthium	12.11 %	17.47 %	70.42 %
Erigeron	13.08 "	17.9 "	69.02 "
Solidago	10.22 "	18.36 "	71.42 "
Wet region:-	7.7 "	30.5 "	61.80 "
Same order	10.87 "	52.43 "	36.70 "
as above.	9.- "	26.20 "	64.80 "

The same thing seems to be more

or less true among trees. The cottonwood, a tree which invades the dry regions farthest, shows a larger percent of cortex than any other tree studied. For a single year's growth it is as follows:- bark 30.72 percent; wood 33.30 percent, pith 35.98 percent. This may not be true of all plants but as a general rule it seems to be one of the most constant of variations resulting from water-supply. What can be the reasons for it? First the outer part of the bark ~~is~~ by its proportionate thickening affords greater protection from drying up. The remainder by thickening serves for the storage of water and food material. The cell in many plants of the dry regions are filled with mucilage which absorbs water readily and gives it out again slowly thus carrying the plant over a long dry spell. Plants of this character also on the average show the storage of a large food supply and the bark seems to be the place where the greatest amount is located.

The wood fibre in dry regions although reduced in extent may be harder and tougher. The number of water tubes is usually increased and their size diminished yet this does not seem to be absolute and an indefinite number of observations would be necessary in order to establish the fact as a general law. The following examples may serve to convey the facts about the conditions which prevail in most cases. The figures give the number of water tubes per square millimeter for spring and fall growth and for the annual ring with each species of plant both in the drier and wetter region.

Helianthus annus	Spring	Fall	Annual ring.
Dry region	224	201	2125
wet region	119	49	168.

	Spring	Fall	annual ring
Xanthium Can			
Dry region	97	58	77
Wet "	65.71	47	53
Erigeron Can.			
Dry region	348	234	291
Wet "	348	187	241
Rhus glabra			
Dry region	201	110	[illegible]
Wet "	149	140	1.33
Sambucus Can.			
Dry region	245	281	263
Wet region	206.8	255	268

Again plants which have on the average large water tubes show a greater variation that those with small water tubes. Although we have not had an opportunity to prove it by experiments the following ought to be true:— plants growing in hot wet regions should be the best addapted for water carying while those in cool dry regions should show the least modification for this purpose. With a high temperature the rate of transpiration rises rapidly. In a wet region water can be obtained to supply this transpiration and the plant should be well prepared for getting this water up to the leaves where it is evaporated. Furthermore we have what appears to be proof of this in the luxuriant vegetation of the wet tropical regions. Along with the water must come up a great amount of raw food material which is left in the leaves and produces the extremely rapid growth.

Dropping the effect of water for the present it might be well in this connection to further mention that temperature may also have other effects than increasing evaporation. Plants have their maximum and minimum temperatures between which they thribe best and this determines upon what part of the earths surface they will grow and as the temperature varies with the seasons in the different regions in which they grow their annual growth is correspondingly affected.

Again the nature of the soil affects the plant not only as we have shown by the amount of water it contains but also by the amount of food material it contains of the nature required by the plant. A plant may show great variations on this account when everything else is equal.

Plants also show great variations in their growth brought about by their rivalry with other plants growing in the same area. The more crowded plants are the more slender they grow and the more they streach up for light. The more plants of the same kind that are growing together the greater the effect for greater is the struggle for existence. A plant reaches its most perfect growth when its neighbors are cooperative rather than competitive or of an entirely different nature in growth or when the plant has the region entirely to itself.

Let us now turn to another side of the subject. Let us leave the effects of water, soil, heat, light and all of the other factors which affect growth and notice the variations in plants and their structure characteristic of their nature and reproduction.

An annual or herbaceous plant differs from a woody perennial in that the wood is less compact and thinner in proportion to the entire cross section of the stem. The amount devoted to pith or medula is greater running frequently as high as seventy or eighty percent of the diameter in cross section while in trees it will not average much more than half as much. Thick plates of the same tissue in herbaceous plants frequently divide the zone of wood into wedge shaped sections and the medulary rays are never as perfect or highly differentiated as in woody plants. There is also a great difference in regard to the storage of food materials. Annuals do not store up large amounts of reserve food in the stem like perennials except in a few cases and these are in plants addapted to dry regions. Trees usually show large amounts of starch in the xylem, in the medullary ray cells, in the wood parenchyma and in some cases, as for example the willow where the latter are lacking, in the ordinary wood cells. In annuals however starch when it is stored is rarely ever found stored in the xylem. It is stored in the cortex or in a ring just inside the xylem. A good example of the first is found in Amaranthus retroflexus and lividis and of the latter in Datura stramonium and Polygonum Pennsylvanicum. The reasons for these things are that the annual has no need of food stored in the stem for the stem dies at least with the coming of frost. Trees on the other hand must provide for the nourishment of the living cells during the period when no food can be manufactured by the leaves and also for the production of the first new leaves in spring. Annuals since they depend upon seed for the continuation of the species must turn their entire energy to the production of seed and the food material as it is manufactured instead of being stored up in the stem is used for this purpose.

The extent of growth in annuals is, as we now see, determined in one way by the length of time required for the production of seed. After the seed are produced the plant dies. There is no resumption of growth after it has onced ceased as is the case in trees or shrubs. For this reason also there is no demarkation in annuals into layers or rings as in trees. For the reason that growth probably never entirely ceases until death or until seed have been produced there can be no true rings of growth. There are apparently thicker and thinner places in the woody tissues of herbaceous plants but these never take the form of well marked rings.

In trees it is different. The leaves may fall. Growth may entirely cease and then be resumed again suddenly producing distinct ~~rings~~ demarkations of the wood into rings. These rings are not however as is often supposed the distinguishing marks of a year of growth. They usually indicate a year's growth but not always for frequently they become very uncertain and indistinct especially on the lower or side branches of trees where growth is slow. Nor can the rings of bud scales be taken as a certain indication of the limit of the years growth. These may be formed in the center of the seasons growth with green leaves both above and below. Such was found to be the case during even the exceedingly wet summer of nineteen hundred and two in a number of trees such as the ash, white poplar, Osage orange and mulberry. Again in regard to the rings in the wood; in the topmost branches of a tree which is growing very rapidly pseudo-rings are frequently formed which to the eye have all of the appearance of perfect rings but under the microscope fail to show all of the characters of a ~~real~~ true ring. The real and pseudo rings sometimes approach each other so closely however that they can scarcely be distinguished with certainty in all cases Finally the conclusion seems justified that both rings in the wood and rings of bud scales may be formed if there is sufficient check in the growth. Yet rings of bud scales are the first to appear in consequence of such a check and may appear when only pseudo-rings are formed in the wood.

J. E. Courtright 1903